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Modeling of Tumor Location Effect in Breast Microwave Imaging Using COMSOL

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Abstract: Microwave imaging has been recently proposed as a potential candidate for breast cancer screening. This method detects abnormalities in the tissue based on permittivity difference between healthy and malignant tissue. In this technique breast is illuminated by high frequency electromagnetic wave, and received signals are then analyzed in order to reconstruct a map of breast's permittivity. In this paper, a simplified 3D breast microwave imaging is simulated, and the effect of tumor location, size and permittivity are studied.

Keywords: microwave imaging, breast cancer, antenna, scatter, tumor location

1. Introduction

According to Canadian Cancer Society, breast cancer is the most frequently diagnosed cancer in women with over 23,400 new cases expected in 2011 [1]. Our ability to potentially detect breast cancer in an early stage has potential of significantly decreasing mortality. Therefore, early detection is a very important issue in healthcare. Mammography has been used widely for screening women over 50 who are more vulnerable [2].

However mammography suffers from some limitations such as false negative and positive results, using ionizing radiation and patient's discomfort [2], [3]. Microwave imaging has been introduced recently to overcome drawbacks of this method. It is based on electromagnetic properties difference between normal and malignant tissues in microwave frequencies. In this method breast is illuminated with high frequency waves and scattering waves are measured by receiving antennas. Measured signals are analyzed to build permittivity map of breast using various image reconstruction methods [4]. In this paper, a simplified 3D forward simulation of a breast microwave imaging is performed, and the effect of tumor existence and its location, size and permittivity on measured signals from receiving antennas are studied.

The outline of the paper is as follows. In Section 2 we present computational models of electromagnetic wave propagation in breast when tumors are absent and present. In Section 3 we discuss how the aforementioned models were implemented using COMSOL. In Section 4 we present the simulation results and discuss their potential use for inverse problems. Section 5 concludes the paper.

2. Microwave Imaging

In breast microwave imaging the imaging system consists of an array of antennas which can serve both as transmitting and receiving antennas. Therefore it is possible to illuminate object of interest (breast) from multiple directions thus obtaining a full three dimensional scan whose resolution depends only on the number of antennas. This process is mathematically described by Maxwell's equations which in this particular case can be reduced to the phasor form since microwave antennas operate in a single-frequency mode.

It should be also noted that the malignant tissue can be mathematically modeled as electromagnetic scatterer. Therefore in the remainder of the paper we will use term scatterer to refer to malignant tissue.

2.1 Medium without Scatterers

In this case the propagation can be described as:

$$\begin{aligned}
\nabla \times E &= -j\omega\mu H \\
\nabla \times H &= J + j\omega\varepsilon E \\
\nabla \cdot E &= \rho / \varepsilon \\
\nabla \cdot H &= 0
\end{aligned} \qquad (1)$$

where E is electric field intensity, H is magnetic field intensity, and ω, J, ε, μ and ρ are angular frequency, current volume density, medium's permittivity and permeability and volume charge density respectively.

In a source-free medium where $\rho = 0$ wave propagation can be represented as:

$$\begin{aligned} \nabla^2 E + k^2 E = 0 \\ \nabla^2 H + k^2 H = 0 \end{aligned} \tag{2}$$

in these equations k is wave number and expressed as follows:

$$k = \omega\sqrt{\mu\varepsilon} \tag{3}$$

where ε is medium's permittivity and generally is a complex number which is described by:

$$\begin{aligned} \varepsilon = \varepsilon' - j\varepsilon'' \\ \varepsilon'' = \frac{\sigma}{\omega} \end{aligned} \tag{4}$$

where σ is the conductivity of tissue.

2.1 Medium with Multiple Scatterers

Consider N scatterers in a homogeneous medium as it is shown in Figure 1. Each scatterer in general can be described by its location and shape parameters (e.g. for a sphere a single parameter representing radius is sufficient). Note that arbitrarily shaped objects can be represented using spatial Fourier transform and the corresponding power spectral density.

Figure 1. Medium with multiple scatterers

As electromagnetic properties are not identical for different mediums, proper boundary conditions must be considered when wave propagates from one medium to the other one to hold continuity.

Consider two mediums with different electromagnetic properties as shown in Figure 2.

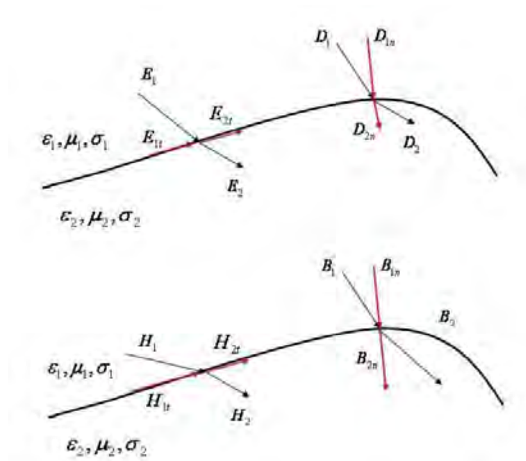

Figure 2. Boundary conditions in electromagnetics

At the boundary following equations are hold:

$$\begin{aligned} \hat{n}\times(E_1 - E_2) = 0 \\ \hat{n}\times(H_1 - H_2) = J_s \\ \hat{n}\cdot(D_1 - D_2) = \rho_s \\ \hat{n}\cdot(B_1 - B_2) = 0 \end{aligned} \tag{5}$$

In summary, above equations indicate that the tangential component of E field and the normal component of B field are continuous across the interface, and tangential component of H field and normal component of D field are discontinuous with the value of surface current and surface charge respectively.

3. Use of COMSOL Multiphysics

To study the effects of tumor geometric and electromagnetic properties on the output of receiving antennas in microwave imaging, a preliminary 3D model is proposed. Simulation has been done in Electromagnetic waves of COMSOL's Electromagnetics module. In this study breast is modeled as a sphere with radius of 100mm as shown in Figure 3. One antenna which acts as a transmitter is located on one side and nine receiving antennas are distributed on the other side of the sphere. These antennas are slim cubes which are centered on the surface of the sphere. Then these cubes and sphere are coerced to solid and interior boundaries are deleted. In this study the operating frequency is arbitrarily set to 4GHz.

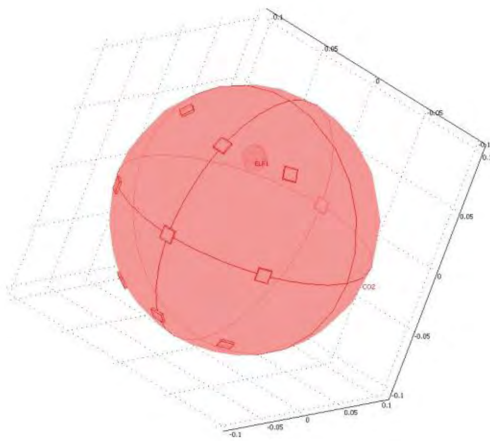

Figure 3. Geometry of simulation

Three boundary conditions are used to send waves in the medium. Electric field is applied to transmitter antenna. Perfect electric conductor boundary condition is applied to sides of antennas in order to guide wave through them, and scattering boundary condition is applied to the rest of surfaces to let waves propagate freely.

Afterward, for different studies one or multiple tumors with arbitrary shapes can be modeled. In this study tumor is considered as a sphere inside the breast with an arbitrary size and in arbitrary position. Three different studies are done using this model: effect of tumor location, tumor size and tumor permittivity. As an example of wave propagation in simulation, in Figure 4 y-component of electric field is shown for the case of eccentric tumor. In this figure tumor is located between second and third plates, and scattering electric field is clearly seen around the tumor, and higher intensity of electric field immediately after the source is obvious.

In order to simplify the model and reduce the computational time we make the following approximations. Breast normal tissue is considered homogeneous with the relative permittivity of 10 and scattering from skin layer is neglected due to large number of elements and large computational time if skin scattering is included.

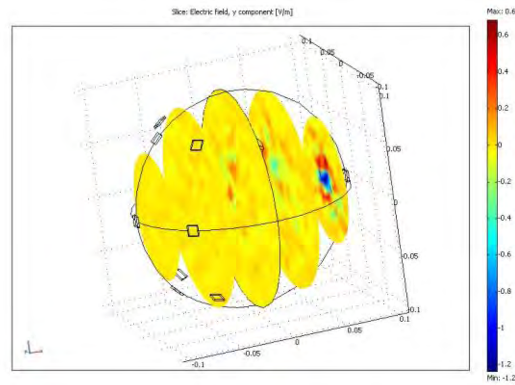

Figure 4. y-component of electric field for eccentric tumor

4. Results and Discussion

In this section results of three above mentioned investigations are presented. In all cases time average power flow on the surface of all receiving antennas is determined by the following equations [6].

$$\text{normPoav} = \sqrt{S^{av}.S^{av*}} \quad (5)$$

where

$$\text{S}^{\text{av}} = \frac{1}{2}\text{Re}(E \times H^*) \quad (6)$$

All outputs are normalized to transmitting antenna power when no tumor is present, and receiving antennas are numbered as shown in Figure 5.

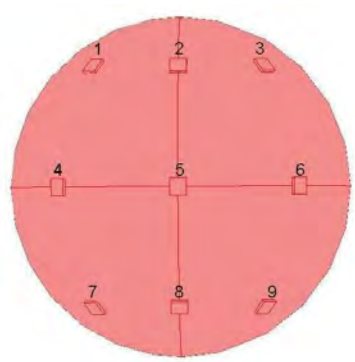

Figure 5. Receiving antennas numbering

4.1 Tumor Location

For the study of the effect of tumor location, three different cases were simulated: no tumor, centric tumor location and eccentric tumor location. Tumor in this study is modeled as a sphere with the radius of 10mm and the relative permittivity of 50. Results are shown in Figure 6.

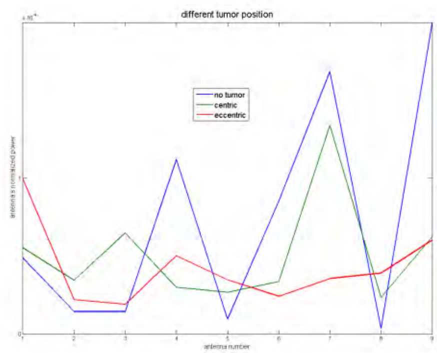

Figure 6. Effect of tumor location on measured signals of receiving antennas

4.2 Tumor Size

In order to investigate the effect of tumor size, tumor radius is changed from 5mm to 30mm with the steps of 5mm, and again average power is calculated on all antennas. Results are shown in Figure 7.

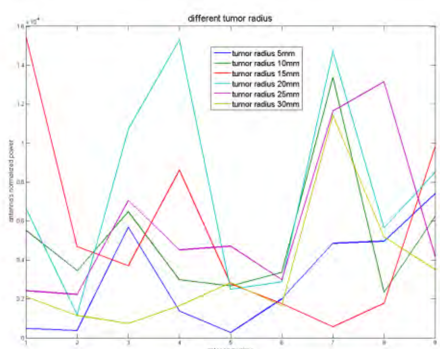

Figure 7. Effect of tumor size on measured signals of receiving antennas

4.3 Tumor Permittivity

In this section we analyze the effect of tumor relative permittivity on output signals. In this case, relative permittivity of the tumor located in the center is changed from 20 to 100 with the steps of 20. Output signals of all nine receiving antennas are shown in Figure 8.

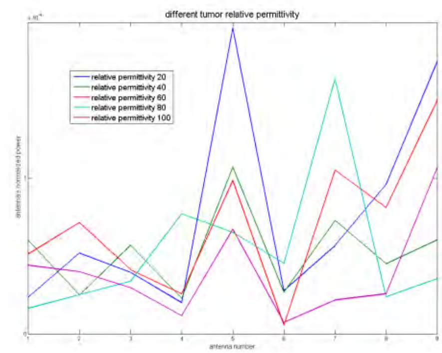

Figure 8. Effect of tumor relative permittivity on measured signals of receiving antennas

Results of this section show that measured signals are dissimilar for different simulated conditions as it is shown in last three figures. In reality, measured signals are mixed with noise, thus proper noise reduction methods must be applied to get better signal to noise ratio. After that, different image reconstruction methods such as gradient method or stochastic methods like Genetic Algorithm can be used to construct permittivity map of the breast for cancer diagnosis purposes [7], [8].

5. Conclusions

Microwave imaging has been recently proposed for breast cancer screening program, but it has not been used in clinical tests yet, and more study is required in this area. Here, 3D simulation of breast cancer was done using COMSOL's Electromagnetic module. No tumor present case and two different tumor locations were studied and the effect of its presence and location is studied on output signals. Also, the effect of tumor's size and permittivity were investigated.

In addition, more studies can be conducted to consider more realistic conditions. In this regard, breast glands with less relative permittivity contrast to tumor and taking into account the effect of skin on results are issues to be considered.

6. References

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